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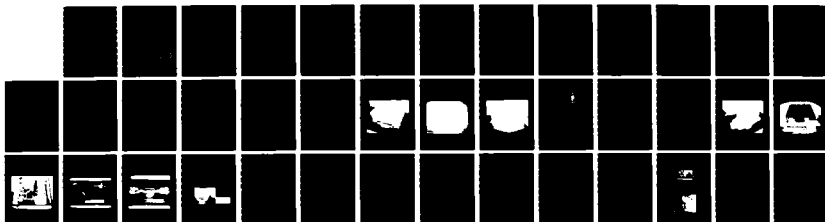
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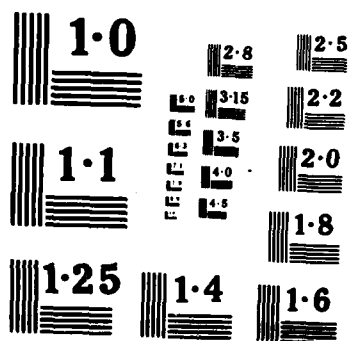
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Balloon Instrumentation Engineering and Development

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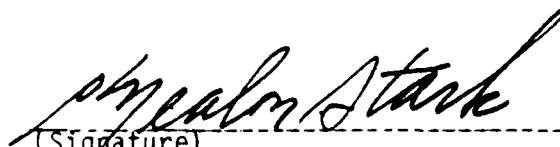


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## BALLOON INSTRUMENTATION ENGINEERING AND DEVELOPMENT

### I. INTRODUCTION

This is the final report for Contract F19628-82-C-0041. It summarizes the various activities performed, which were described in greater detail in previous reports during the course of the contract. In particular, these activities involved:

- (1) A High-Altitude Balloon Motion Sensing Package.
- (2) A Tethered-Balloon Instrument Package.
- (3) Computer Programs for Aerostat Dynamics.
- (4) Repair of a 45,000 cubic ft ILC Aerostat.
- (5) EV-13 Helium Valve Research
- (6) Balloon Ballast Valve Redesign.
- (7) Development of an Omega/Met Balloon Tracking System.

All of the above topics, except (3) and (4), resulted in hardware which was delivered to AFGL. Topic (4) involved a large tethered aerostat which had been shipped to UTIAS for rehabilitation and which was later returned to AFGL's operating location in New Mexico. The computer programs developed under topic (3) were stored on 5-1/4 in. computer discs and shipped to AFGL along with program listings and explanatory documentation.

### II. DESCRIPTION OF SPECIFIC ACTIVITIES

The activities carried out in connection with the topics listed above will now be synopsised in turn:

#### (1) High Altitude Balloon Motion-Sensing Package

The motion of a high-altitude balloon at float altitude is usually an important consideration in the design of scientific payloads. This motion consists mainly of vertical oscillation of the balloon system about the float altitude, rotation about a vertical axis, and pendulation of the suspended payload. Although individual experimenters have measured balloon motion with a variety of techniques, the resulting database is small and uncorrelated.

In 1983 UTIAS undertook to develop an instrument package capable of measuring the various aspects of balloon motion. This motion-sensing package would be flown on AFGL balloon flights to collect data that would be assembled into a comprehensive database for general use. The instrumentation would be self-contained, operate from battery power, and would provide analog outputs compatible with existing AFGL telemetry equipment. Using their experience in the development of sensor packages for determining aircraft motion, UTIAS came up with the following design.

The motion-sensing package uses a triad of orthogonally-mounted Honeywell GG440 A7 rate gyros to sense the angular motion of the balloon. In addition, the balloon's translational motion is detected by a similar triad of Sundstrand GA-1100 accelerometers. Finally, a Schonstedt SAM-73C



three-axis magnetometer provides an indication of the balloon's absolute orientation with respect to the earth's magnetic field. The rate gyros and accelerometers are maintained at a temperature of 50 degrees Celsius to minimize temperature effects on sensor performance.

Since the expected magnitudes of balloon motion are very small, only a small part of the accelerometer's and rate gyro's dynamic range would be used. To obtain better resolution, two channels of amplification are used for each accelerometer and rate gyro. This results in full scale ranges of  $\pm 1$  and 0.1 degree/second for the rate gyros and  $\pm 0.5$  and 0.2 g for the accelerometers. The accelerometer that senses vertical acceleration is a special case since, at equilibrium, it indicates a force equal to the earth's gravitational attraction. In order to measure only the balloon's vertical acceleration, the gravity signal is cancelled out by combining the accelerometer output with a stable reference voltage. The six accelerometer and six rate gyro outputs are low-pass filtered to reduce aliasing effects during data sampling.

The sensors and signal processing electronics are housed in a pressure-tight aluminum enclosure (Figure 1). Two large bubble levels and adjustable pads at the corners enable the package to be levelled to a fraction of an arc-minute. Input power, control signals, and output signals are routed through one of the Cannon connectors on the instrument package. The other one is connected to an external 400 Hz converter that powers the rate gyros. A top view of the motion-sensing package with the cover removed is shown in Figure 2. The accelerometers and the rate gyros are shown inside their enclosure, while the magnetometer is the oblong object in the upper right of the picture. A front view of the package without the cover is given in Figure 3.

The motion-sensing package was flown on a balloon flight from Holloman AFB, New Mexico in October, 1983. Good telemetry data were obtained throughout the six hour flight. The data were stored on magnetic tape and sent to UTIAS for analysis. The instrument package was recovered after the flight and showed no deterioration in performance due to the flight.

Data analysis revealed that the sensors performed admirably. The balloon pendulation rates measured by the X and Y axes rate gyros at float altitude are shown in Figure 4. These rates are less than 0.05 degrees/second, and the resulting angular displacements obtained by integrating the gyro rates are also quite small. The azimuthal rotation measured by the Z axis rate gyro is much larger (see Figure 5). The bottom plot shows good agreement between the azimuth angle indicated by the magnetometer measurements and that obtained by integrating the Z axis rate gyro signal. Figure 6 shows vertical acceleration of the balloon, along with the corresponding velocity and displacement plots obtained by successive integration of the acceleration data. There was almost no activity on the two horizontal accelerometer channels, and what little there was proved to be due to the pendulous angular accelerations of the balloon gondola.

Several improvements were made to the motion-sensing package before it was turned over to AFGL in 1985. The rate gyros were replaced with Honeywell GG440 B1 models, which have about twice the sensitivity of the

A7's. Since the magnetometer used had been obtained on loan from the National Research Council of Canada, AFGL Purchased a new one from Schonstedt. This was sent to UTIAS and installed in the motion-sensing package. Anti-aliasing filters were added to condition the three magnetometer outputs. Finally, a custom-built DC-DC converter was added to allow the instrument package to use a unipolar power supply. This converter is mounted externally with the 400 Hz gyro power supply (Figure 7). A comprehensive user manual was prepared which completed the documentation for the project.

## (2) Tethered Balloon Instrument Package

An instrument package has been designed and built for tethered balloon applications. This instrument package is capable of measuring the pitch, roll, and yaw motion of the balloon. Temperature measurements can be made at points on the aerostat hull as well as inside the helium chamber and the balloonet. In addition, the package can monitor the pressure in the helium chamber, the balloonet, and the fin as well as the tether tension and tether angle. Most of the sensors and electronics are housed in an aluminum enclosure that is designed to be rigidly fixed to the belly of the aerostat (Figure 8). The unit is powered from external batteries and signal outputs are designed to interface with AFGL telemetry equipment.

Figure 9 shows the internal layout of the instrument package. Pitch and roll of the aerostat is measured by a Humphrey VG24-0801-1 vertical gyro, while yaw is sensed by a Humphrey NS06-0101-1 north seeker. Three Setra Model 239E pressure transducers are mounted in the package. Tygon tubing is used to connect each pressure sensor to the measurement points on the aerostat. The package contains five thermocouple amplifiers that condition the outputs of the thermocouples placed at various points on the aerostat. Two of these copper-constantan thermocouples are used to measure the helium-gas and balloonet-air temperatures, while the other three are employed to monitor aerostat skin temperatures. These transducers are shown in Figure 10.

The tether tension is measured by a Sensotec load cell located at the confluence point (Figure 11). This is a strain gauge device with a capacity of 5000 pounds. Mounted to the load cell by a bracket is a Humphrey CP17-0601-1 pendulum (Figure 12). This potentiometric device indicates the angle the tether makes with respect to the vertical. Separate cables provide electrical connection between these sensors and the instrument package.

The instrument package uses four heavy-duty latches for quick connection to a plate fastened to the aerostat's belly. Separate connectors are provided for the power/control lines and the output signals. The other three external connectors are for the load cell, pendulum, and the thermocouples. The wiring has been completed so that the instrumentation can be used with the ILC 45k aerostat that was worked on by UTIAS.

Calibration tests on all the sensors have been completed and the results have been included in a user's manual for the tethered balloon instrument package. All hardware and documentation have been sent to AFGL at Hanscom AFB, Massachusetts.

### (3) Computer Programs

A number of programs have been developed in BASIC on the HP86 computer to analyze the stability of the STARS aerostat. These programs have been provided to AFGL on two floppy disks. Listings and documentation were provided with these disks. All printouts are for 80 column printers.

Included is a program that determines the trim configuration of the aerostat under various atmospheric conditions, producing 3D projections of the aerostat on the computer screen. Also included are programs that calculate the stability derivatives, stability roots, and turbulence response of the aerostat. Some of the stability programs treat the tether as a massless, dragless rigid rod while the others use a dynamic tether model.

### (4) Repair of 45k ILC Aerostat

This report details the work done on the ILC 45k aerostat from May to July 15, 1985. The balloon was housed in the 'dome'--a circular covered structure with a 12' wide plywood track around its periphery. The track was cleaned by broom and was covered with a combination of heavy polyethylene sheet and woven polyester tarps. This was also used to cover the balloon when no work was being done on it.

Work commenced at the beginning of May and involved laying out the fins, inspecting them, and making the necessary repairs. It was found that the glue used on the fin loop patches had degraded and was failing in places. In the worst cases the glued surfaces had separated and appeared black with dirt or mold. The glue and dirt were extremely difficult to remove without damaging the fabric; without a clean surface, a good bond using the Shore-UBS 1087 adhesive could not be made.

It was decided to simply cut a patch about 2" in diameter larger than the existing patch and glue over the old patch. This would give a fair amount of clean material to glue to and would prevent the original patch from further degradation. Those patches that had begun to peel were cleaned and reglued as well as possible. The area was scrubbed with a water soluble liquid cleaner before glueing. The tape around the fin zippers had also been seriously soiled and was in poor shape. It was very easy to pull off. The worst was pulled off and then the area was cleaned and reglued with new tape. This gave reasonably good results.

The T-tape of the catenary web was inspected and was found to be coming free from the fin material in a number of places. Again, the tape was reglued where necessary but this time the glue did not grip as well as in the previous cases. Adding more glue did not seem to make a difference. The strength of the bond seems to be adequate though, because in the late summer of 1984, when the T-tape problem was first discovered while the balloon fins were inflated to 2 iwg, a section of tape two to three feet long was reglued in the manner described, and the fins were successfully pressure tested to 4 iwg for an hour.

Reglueing was also done at the root of the fins where the seam was in poor condition. The glueing results here seemed to be quite good. Note also that the dirtiest spots on the fins were cleaned.

Silicon sealant was applied to the base of the fin loops in an attempt to seal the fins better because, during inflation tests, the Joy blower had a hard time maintaining a pressure over 2 iwg. One hole was cut for a Stratotech breather valve, where the fin was reinforced with a ring of material. There were two indicated locations, on the port and starboard "trailing edges", quite near to the root. The cut-outs for the fin and ballonnet blowers were done previously.

The ballonnet access tube was badly torn so a new one was made and the old one cut off. The new tube was installed by slitting the end in about eight places to make petals so that it could be stretched to a larger diameter for glueing. A ring of tape was glued to the tube where the petals stopped to prevent any tearing. Next, a ring of hull fabric was cut and the petals of the tube were glued to the hull and then covered with the ring of hull material. The procedure gave good results; the access tube was used a few times after this and no problems were found. A small pin-hole on the hull was patched.

The next major piece of work was the load patch and plate for the tethered balloon instrument package. The plate is an octagonal piece of 1" fir plywood, 3' wide across the flats. The top edges were planed and sanded round to prevent the flaps of the patch from creasing. Thirty-two Holt-Allen plastic lashing hooks were fastened to the plate with brass #6 x 1" flat head screws. Aluminum brackets for fastening the instrumentation package were mounted to the plate with stainless steel #10-32 x 1.5" flat head screws with a lock washer and nut. The plate was painted with two coats of exterior white paint.

The load patch was based on the ones used for attaching the control boxes, but this time no T-tape was available. The patch was made by a series of cuts and folds from two pieces of hull fabric with reinforcing circles of material where each point of the plate met the fabric. The folds were glued with Shore-UBS adhesive. Brass #2 spur grommets were installed. A sample of the hull material was stitched to determine if it was worthwhile to stitch the bottom of the patch's folds for some insurance. The holes put into the fabric by the needle and the associated rubbing and pulling by the thread seemed to cause too many problems so no stitching was done.

The patch was placed where the tangent to the balloon hull was parallel to its longitudinal axis; this was determined from the drawings by counting seams and then finding the same seam on the balloon. Gore dimensions were checked against the drawing and the agreement was fairly good. Once the wiring harness was cut out from the patch area, the patch was glued down, one third at a time.

Ports for the thermocouples and pressure taps were made. A backing plate was installed by glueing it to the inside of the balloon and then glueing a piece of fabric over the plate and to the hull to sandwich the plate. A cover plate was installed and then covered with duct tape to prevent the screw heads from damaging the balloon. The control boxes had

their Dwyer pressure switches installed with the diaphragm in a vertical plane as directed in the installation sheet. The switches were set to 2 iwg. Power connectors were installed along with fittings for 0.25" Tygon tubing. Stainless steel fasteners were used throughout. Heyco liquid-tight connectors were used to bring the Tygon tubing through the wall of the box. These connectors have a plastic collet with a neoprene sleeve that can be tightened against the tubing. The collet has a small plastic pawl that prevents loosening unless it is broken off.

A welded edge of the fin-pressure box was failing and had to be rewelded. Also, aluminum covers were welded to the boxes to seal up some unused holes that had been drilled for a different pressure switch. Note that the ballonet box uses a nickel-plated button to plug a hole.

A power connector was fastened to the strobe by using a 3M synthetic rubber cement to glue the grommet to the rubber bushing of the connector. This helps to weatherproof the case. Pin B on the connector is for the negative or black lead.

A data sheet on the 3M adhesive was sent with the balloon along with two samples. The initial strength of the glue does not seem to be as good as the Shore-UBS 1087 because the adhesive tends to peel away from the smooth white surface of the hull material. However, leaving the bond to age over the weekend made a big difference. Pulling the bond apart with pliers caused the material, but not the adhesive to fail. It definitely deserves some looking into, especially since it is safer to work with than the Shore-UBS. The 3M people say that this glue is used for joining mining belts and has good adhesion to urethane.

#### (5) EV-13 Helium Valve Research

This report is a summary of the research relating to the EV-13 helium valve that was carried out at UTIAS during the time period of April 1983 to June 1984. In particular, the mass-flow characteristics of the valve were studied, and various modifications were examined that could contribute to the improvement of the valve's performance.

It was intended that the data gathered from these experiments could be used to obtain better control over descent rates and to improve valve efficiencies during balloon flights. There are three possible sources of error that could affect the validity of applying the discharge data collected from the test apparatus to a balloon at flight altitude. They arise from the fact that the discharge coefficients may vary with the following parameters:

##### [1] Approach velocity of helium

The approach velocity in a large volume balloon is essentially zero. Thus the approach velocity in the test cell should be close to zero to eliminate this source of error. This was accomplished by creating a large plenum chamber that separated the valve from the input flow area with the use of fine screen baffles. The result was an almost purely static pressure condition at the valve, and all attempts to measure the approach velocity resulted in immeasurably small quantities.

## [2] Density changes across the valve

The fact that helium is being discharged into air during a balloon flight, as opposed to air discharging into air for the test cell, is thought to cause very little error since both gases approximate the ideal gas laws under both sets of conditions. The validity of this assumption has not yet been tested using the valve test cell.

## [3] Absolute pressure

This source of error will be minimal if the ratio of absolute pressures is greater than 0.95. It was demonstrated by H. W. King in "Hydraulics" that the change in discharge coefficients is only 0.5% for an absolute pressure ratio change from 1.0 to 0.95. In particular, for a balloon at an altitude of 100,000 feet, the absolute pressure ratio is  $(4.7" \text{ H}_2\text{O}) / (4.73" \text{ H}_2\text{O}) = 0.9958$ . For the test apparatus at STP, the ratio is  $(4.06" \text{ H}_2\text{O}) / (46.92" \text{ H}_2\text{O}) = 0.9999$ . Therefore, it appears reasonable to assume that the valve data collected from the test cell may be applied to a balloon flight at altitude provided that the apex pressure differential can be accurately measured.

## Test Apparatus

The test apparatus used to measure the flow characteristics of the provided EV-13 valve underwent a series of improvements during the period of investigation. The valve apparatus consisted of three basic elements: a large plenum chamber that creates a pressure difference across the valve, a source of inlet air (typically in the form of an axial fan) to produce the increased plenum pressure, and devices to measure the pressure drop across the valve and the mass flow rate through the valve. All three areas were modified during the course of the research to provide more accurate discharge data.

The original test cell consisted of an 80" x 36" x 36" box fitted with an axial fan at one end and the helium valve in a position midway along the box length. Two screens separated the fan inlet area from the valve in an attempt to reduce flow swirl and turbulence created by the axial fan. A plexiglass pipe, 30 inches long by 4 inches in diameter, was located directly over the inlet of the axial fan. A pitot tube, mounted on a calibrated traversing rig, was attached within the pipe so that the velocity profile of the flow inside the pipe could be measured. This velocity profile was then integrated with respect to the cross-sectional area of the pipe to yield the mass flow rate through the pipe, which is also the mass flow rate through the valve. A smooth velocity profile was ensured by placing a 'honeycomb' flow straightener at the top of the plexiglass pipe. Static pressure taps were located around the box to provide a means of measuring the pressure differential between the interior of the test cell and the atmosphere. A Betz manometer was used to monitor these static pressure ports as well as the velocity profile of the inlet pipe via the pitot tube arrangement. The axial fan was chosen to provide steady low pressure differentials in the range of .004 to .02 inches of water at valve openings of 0.4 to 2.0 inches. These pressure differentials correspond to those that the helium valve would encounter at flight altitude. For valve

openings of 2.0 to 4.0 inches, a more powerful centrifugal blower was initially chosen to provide these same pressure differentials.

#### Modifications of Test Apparatus

The first modification to the test setup was to make full use of the plenum chamber's volume by moving the valve to the end of the plenum box. This doubled the chamber volume and allowed a greater separation between the inlet flow and the valve. A new set of interior screens covered with a double layer of cheesecloth was installed to further still the inlet air flow and reduce turbulence. In addition, the fan inlet position was moved so that it was on top of the plenum chamber rather than on the end. This slowed the flow even more, producing valve approach velocities closer to zero. Figure 13 illustrates the original and final apparatus configurations. Tests on the high flow-rate centrifugal blower indicated that steady velocity profiles could not be obtained. As a result it was decided to use an axial fan that was capable of supplying flow rates of 300 cfm, compared to a maximum of about 100 cfm for the other low flow-rate axial fan. Conventional cooling fans were unacceptable since they have AC induction motors whose speed is difficult to control. A DC motor was preferred, so an Astroflight DC motor was modified by adding bearings and cooling vents in its casing and combined with a simple plastic model propeller 6.5 inches in diameter. This combination was capable of producing flow rates greater than 300 cfm. A special aluminum tube and honeycomb arrangement, similar to the one for the smaller axial fan, was constructed to straighten the flow.

The accuracy of the data collected in the low differential pressure range was increased by replacing the Betz manometer with a differential pressure transducer. This was a Setra Systems 239 differential pressure sensor, capable of measuring differentials as low as 0.07 mm of water. The transducer was used for all pressure measurements in the low range, including the velocity profile ones. The plenum chamber was modified for flow visualization experiments by installing airtight plexiglass viewports above and beside the valve. A 'smoke-wand' and a smoke generator were redesigned for use in the plenum chamber.

#### Tests and Results

Preliminary tests that were run consisted primarily of calibration and verification of the pressure transducer and flow velocity profiles. A number of tests were run to find the 'normal' valve flow characteristics at low and high differential pressures for a range of openings. Various valve modifications were then introduced and their effects on the valve's performance were studied. The parameters varied were valve opening, pressure differential across the valve, and mass flow rate through the valve. Mass flow rates were used instead of discharge coefficients because they provided a simple means of comparison between configurations. They are also directly proportional to the discharge coefficients.

Each test run involved:

- setting the valve opening to a predetermined value

- varying the mass flow rate through the valve by stepping the fan through its speed range
- for each fan and valve setting, taking measurements of the pressure difference across the valve and the flow speed using either the pressure transducer or the Betz manometer.

Results are presented for the following valve configurations.

[1] Strobe attached to the valve

A strobe light was mounted on the cross-brace of the valve, with the valve in its normal orientation, i.e., with the valve dome facing inward. As shown in Figure 14, the strobe had minimal effect on valve performance for the range of valve openings and differential pressures considered.

[2] Valve orientation reversed

It was discovered that the valve's efficiency could be improved by up to 26% by reversing the valve's orientation to the flow so that the valve dome faced 'outward' on the plenum instead of 'inward'. Table 1 lists the percentage improvement in mass flow rate for comparable valve openings and differential pressures. Figures 15 and 16 demonstrate these results for the low and high pressure difference ranges. The best results were obtained for small valve openings and large pressure differentials, while large openings with small pressure differences were much less affected.

[3] Modified valve cover

With the valve in its normal orientation, a 13 inch diameter hemispherical plastic dome was attached to the outside of the present cover. The more streamlined valve cover resulted in improved flow rates at the smaller valve openings as shown in Figures 17 and 18 but had a negligible effect for valve openings greater than two inches.

[4] Streamlined cross-brace

The channel support on the valve was streamlined by the addition of cardboard fairings in an attempt to improve the valve efficiency at the larger valve openings. As can be seen from Figure 19, this streamlining had little or no effect on the mass flow rates of the valve. This is most likely due to the fact that, at the low Reynolds number of the flow, the streamlined sections appear as bluff bodies. From these results it seems that the best approach to improving the efficiency of the valve at the larger valve openings would be to reduce the size of the channel support and valve actuator mechanism.

Other investigations

Flow visualization tests were done for the valve in both the normal and reversed orientations to try to ascertain qualitatively the reason for the difference in efficiency. The tests indicated that in the normal orientation the air must encounter the valve dome before exiting the plenum area. The flow was seen to become turbulent upon impinging the cover,



leaving the valve opening in a non-laminar fashion. In contrast, the air exiting through the reversed valve was entirely laminar, hitting the dome cover once it had passed through the valve opening.

The design of a thermostatically-controlled enclosure for a pressure transducer, located on the valve platform, to provide accurate differential pressure readings, was initiated. A controlled environment is required for the pressure transducer due to its sensitivity to temperature changes. For example, at room temperature the transducer is subject to zero shifts of two to four millivolts per degree Fahrenheit. This is not unusual since most pressure transducers have zero shifts of two percent of full scale per 100 degrees F. At pressure altitudes around 100,000 feet the output of the differential pressure sensor will be in the millivolt range, thus necessitating a constant temperature operation. The enclosure was designed to house a Setra model 239 pressure sensor, a temperature sensor, a thermostat, and a heating element. The temperature sensor provides a check on the thermostat and is located next to the transducer. The pressure transducer and thermostat are separated from the heating element by a baffle to eliminate any local heating due to direct radiation. The enclosure consists of an aluminum skeleton lined with two inches of styrofoam. The insulation near the heating element is shielded by bakelite to prevent melting. Calculations have shown that the interior of the enclosure can be maintained at 70 degrees F at a pressure altitude of 100,000 feet and -40 degree F temperature using only 10 watts of power. The heater and temperature controller used for the pressure sensor enclosure is similar to that in the AFGL/UTIAS motion-sensing package.

#### (6) Balloon Ballast Valve Redesign

AFGL's standard device for controlling the flow of finely granulated ballast (steel, lead or glass) has been a lever action valve. It is solenoid actuated and requires a constant 10 volts at 1 amp to remain open. This design not only puts a strain on power supplies; it also provides poor control of flow rates, with frequent overshoots and waste of ballast.

Several alternate designs were examined by UTIAS, but the most attractive solution was to modify the existing lever-type valve, using the motor from the EV-13 helium valve as the electrical actuator in place of the previously used rotary solenoid. The EV-13 motor was already qualified for the high altitude environment, had ample torque and offered substantial power savings. It would be operated in the same manner as with the EV-13 valve, that is, two microswitches would be used to stop the motor at the open and closed positions. If the motor-actuated ballast valve were required to remain open for 15 seconds, it would consume only 2 joules (watt-sec) of power, vs. the 150 joules required by the solenoid-actuated version.

The initial version of the motor-actuated valve had the motor aligned parallel with the solenoid mounting plate and employed a right angle mitre gear to apply torque to the valve lever arm. This was to avoid the 1 in. motor overhang present when the motor is connected directly to the lever arm. (It was feared that the overhang would cause interference when the valve was installed in the ballast hopper.) AFGL subsequently chose the simpler, direct-connection layout as the preferred design, despite the

overhang, and this version (BV-4) was successfully flight tested. Although the valve performed satisfactorily, some difficulty was encountered in setting the limits on the microswitch used to indicate the closed valve position. This difficulty was eliminated by reducing the width of the lever arm and adding an adjustable sliding plate, as seen in Figure 20. This allows the closed-position microswitch indicator to be adjusted after the valve is installed in the ballast hopper.

The substitution of the EV-13 motor for the rotary solenoid in the ballast valve introduced the possibility of metering the ballast flow rate by using the motor as part of a servomechanism. A gear-driven potentiometer was attached to the valve assembly during the course of the redesign effort. Driven from the motor shaft, the potentiometer served as a voltage divider, to allow the size of the valve opening to be varied. The metering idea was set aside, however, when laboratory tests showed a nonlinear relationship between valve opening size and amount of ballast dispensed. Thus, the standard bi-modal (fully open or closed) valve operating procedure was retained. Later on, when the microswitch setting problem surfaced, as described above, the shaft-coupled potentiometer shown in Figure 21 acted as a backup to the open/closed microswitch indicators. The potentiometer was subsequently coupled directly to the lever arm to eliminate the valve position error caused by the small amount of play between the arm and the motor shaft. This valve and drawings were shipped to AFGL in January, 1984, completing work on the effort.

#### (7) Development of an Omega/Met Balloon Tracking System

Certain high-altitude scientific balloon flights must follow a prescribed trajectory if they are to meet the requirements of the experiment being flown. The lack of usable wind information at altitudes above 100,000 ft makes it difficult to predict high altitude trajectories confidently, however, introducing the possibility of mission failure. AFGL had attacked this problem in the 1970's, undertaking the development of a pathfinder system which would use small plastic balloons to sample wind conditions at altitudes of interest just prior to main mission flights. The balloons would carry radiosondes equipped with miniature navigation receivers tuned to the worldwide Omega navigational network. Any received Omega signals would be retransmitted to a ground station where they would be processed and converted to position and wind data. Meteorological data (pressure, temperature, humidity) would be transmitted at the same time and processed separately. The pathfinder system employed the WO-2P LO-CATE system developed by Beukers Laboratories, Inc., as the ground station. Unfortunately, pathfinder development work was interrupted prior to completion and the LO-CATE system was placed in storage. In the early 1980's, when development was reinitiated, the stored equipment was in need of rehabilitation. In addition the Beukers Model 1221 radiosondes produced in the 1970's had been replaced with newer models which were incompatible with the original ground station.

In the summer of 1982 UTIAS was asked to do the following:

- (1) Produce a satisfactory interface between the WO-2P LO-CATE ground station and newer radiosondes (Beukers microsonde series 1500, or

Vaisala Model RS80), either by combining commercially available components or by a new design.

- (2) Determine best line-of-sight performance of the various alternatives under worst case conditions; modify the old ground station as required to achieve satisfactory line-of-sight (LOS) performance.

By December 1982 the following tentative findings had emerged:

- (1) Based on free-space calculations, a range of 350 miles between the radiosonde transmitter and the ground-based telemetry appears possible, with a good signal-to-noise ratio.
- (2) The ground receiver front end should be modified to have AGC, to increase dynamic range and to reduce interference.
- (3) The WO-2P ground station can process Navaid data from the old and new sondes. However, its Met data decoder is compatible only with the older 1221 sondes. Met data decoders should be designed to accommodate both of the newer sondes. This would allow the equipment operator to select the best sonde for the prevailing circumstances. The Vaisala RS80 has greater sensitivity and is more useful in weak signal situations. The Beukers 1500, with its better overload phase characteristics, would be preferred when the signal is very strong.

Work on this task was suspended for a number of months at UTIAS to accommodate higher priority efforts. In the interim, following a decision to concentrate initially on the Vaisala sonde, a Vaisala Met Data processor was ordered for use with the LO-CATE ground station. When work was resumed in September 1983 the ground station was tested operationally for the first time. Good reception of Omega signals was experienced, once an internal short in the VLF receiver was discovered and corrected. Inconsistencies in signal quality were noted from two of the Omega stations, however, and an Omega signal generator was developed in-house to determine Omega signal processor accuracy. Tests with the generator pointed up the need for repairs to the Omega Processor. These were made, assuring perfect Navaid track calibration. Also, a defective amplifier in the VLF antenna coupler was repaired, further increasing sensitivity. By November, excellent world-wide Omega reception was being experienced (Japan, Liberia, Hawaii, N.Dakota, Reunion, Argentina and Australia).

Initial attempts to integrate the Vaisala Met Data Processor with the LO-CATE system failed because of problems with that processor. After factory repairs, the integration was accomplished successfully and Met data processing accuracy was verified. New circuitry was added to the LO-CATE system to facilitate a time-shared differential mode of operation where the sonde signal is periodically compared with local station phase data to reduce the effect of propagation anomalies. Repairs were also made to the Met and Navaid chart recorders. By February 1984, the entire system was in good working order and ready for field test.

In May-June 1984 a timing circuit was designed and built to provide power at a programmed time (0+7.5 min to 0+12 hr, with a 7.5 min resolution) to a hot wire cutter to terminate the pathfinder balloon flight.

The system was field tested at Holloman AFB, NM, in September 1984. In two balloon flights on successive days all available Omega channels (except Norway), in combination with North Dakota as the common channel, provided solid signals for position fixing. Both the sondes and the ground equipment performed well. A problem was encountered with the balloon destruct mechanism, which needs redesign. The electronic timers which initiated the destruct process performed as required, however.

### III. SUMMARY AND CONCLUSIONS

The studies and investigations carried out by the University of Toronto Institute for Aerospace Studies (UTIAS) have focused on balloon instrumentation deficiencies and on problems related to high-altitude balloon and tethered-aerostat operations. As indicated in the foregoing descriptions of the individual research and development efforts, the program has been very productive and has given the U.S. Air Force a number of new instruments and techniques with which to augment its operational capabilities in the fields of scientific and military balloon applications.

### IV ACKNOWLEDGEMENTS

The authors wish to acknowledge with sincere thanks the invaluable contributions of a number of individuals at the Institute to the success of the balloon instrumentation R and D program undertaken for AFGL. Their dedication, enthusiasm and technical creativity allowed each task to be pursued vigorously and with positive results. Mr. Wah Kung played a major role in the development of the balloon motion-sensing package and the tethered-aerostat instrument package. In addition, he and Mr. Ken Wong were largely responsible for the aerostat computer programs prepared for AFGL. Mr. William McKinney carried out the ballast valve redesign effort and collaborated with Ms. Jodi Diamant-Boustead in the EV-13 Helium Valve performance investigations. He also completed the rehabilitation of the ILC 45,000 cubic ft aerostat, with the very able assistance of Mr. David Ahier. Mr. Jake Unger was the driving force behind the Omega/Met Balloon Tracking System development effort and made major contributions to the electronics of the Balloon Motion-Sensing and Tethered-Aerostat Instrument packages. Finally, Mr. Bill Davies was responsible for the preliminary mechanical design of the balloon motion-sensing package.

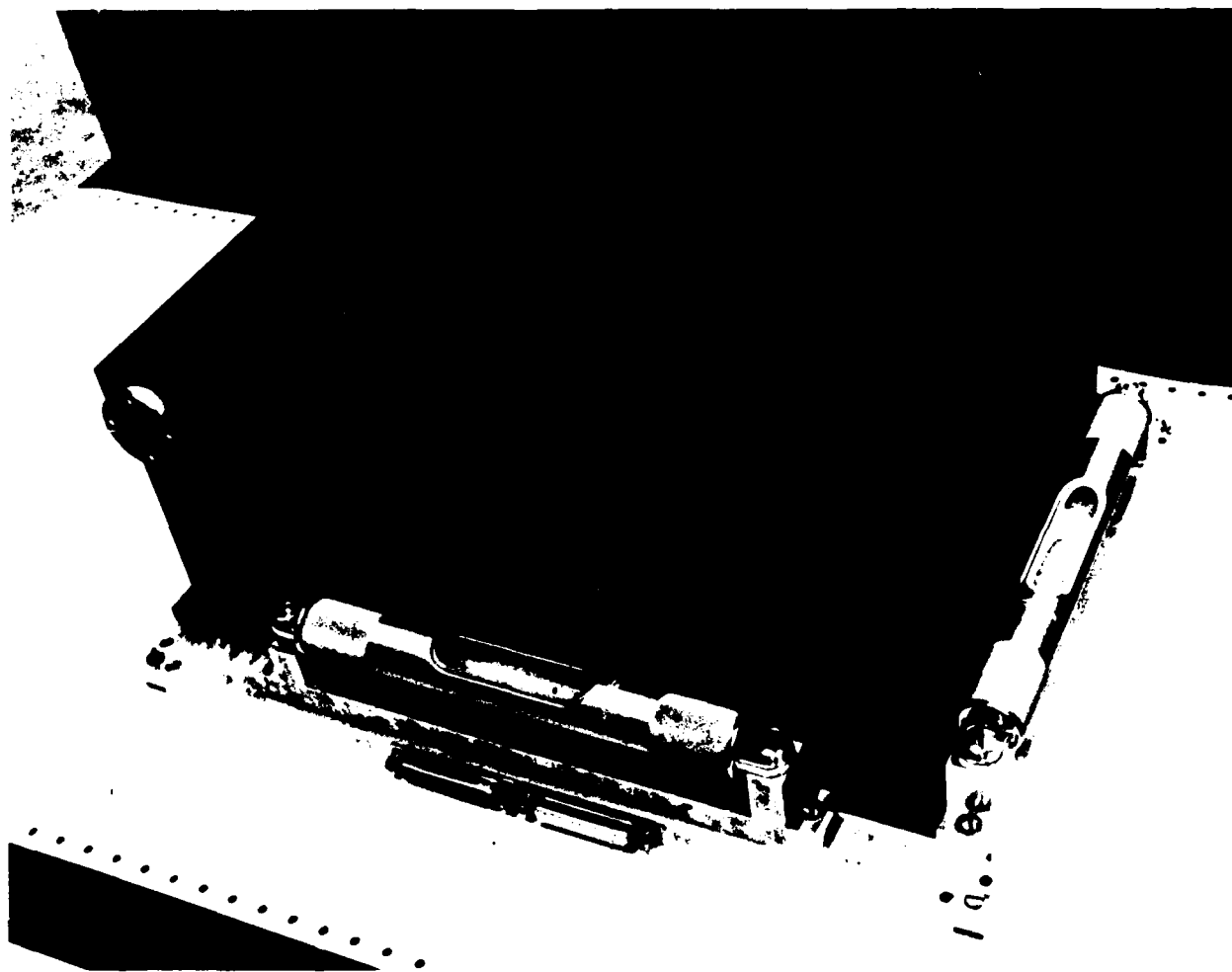


Figure 1: High altitude balloon motion-sensing package

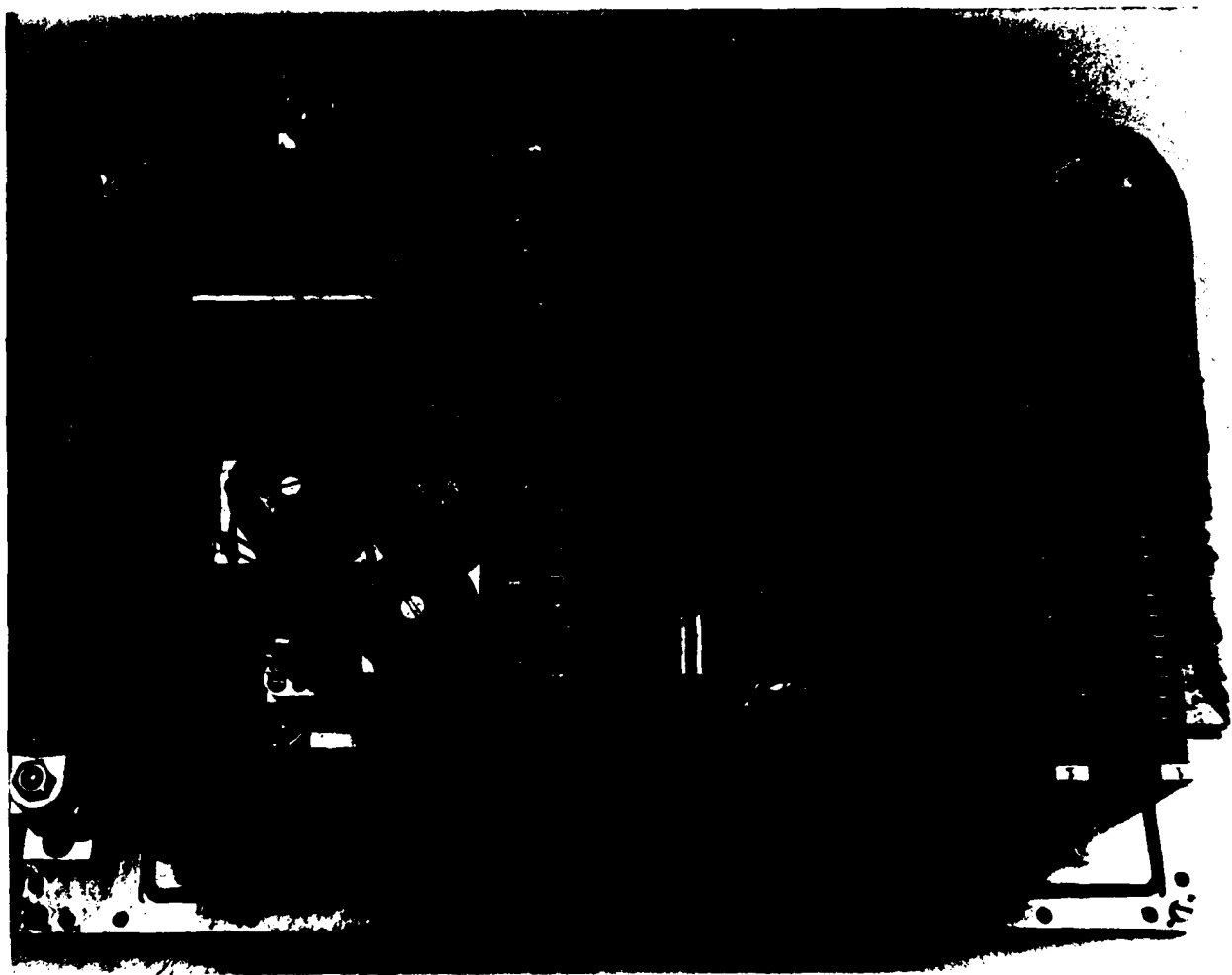


Figure 2: Sensor oven with cover off showing accelerometers and rate gyros

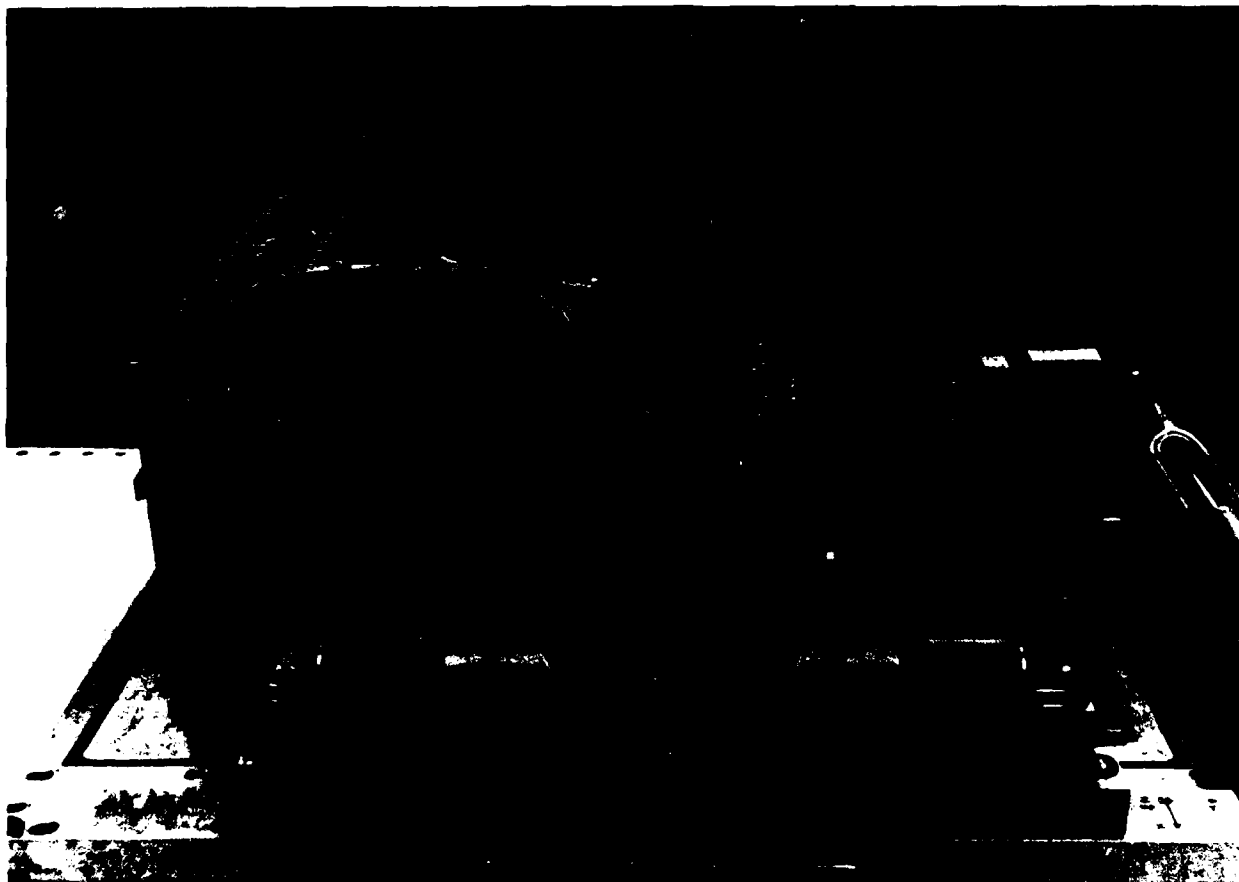
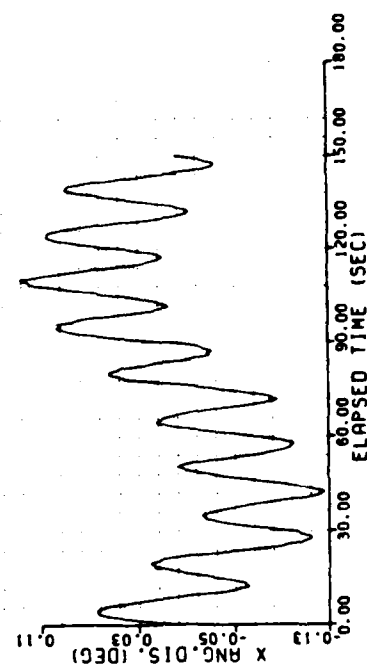
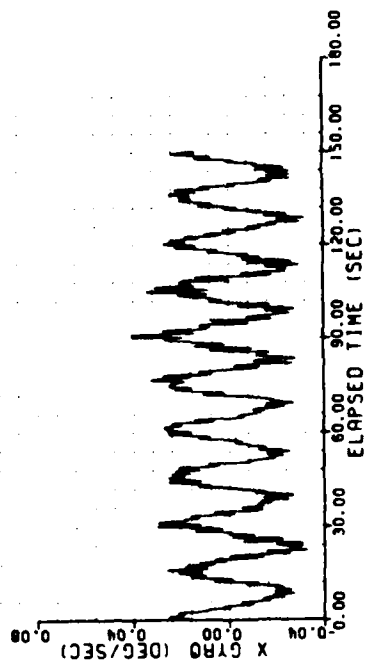
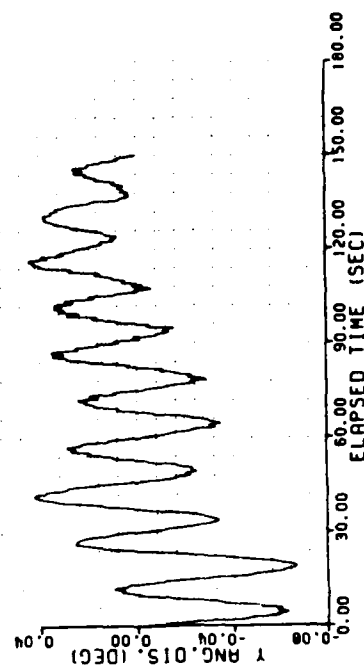


Figure 3: Front view of package with cover off

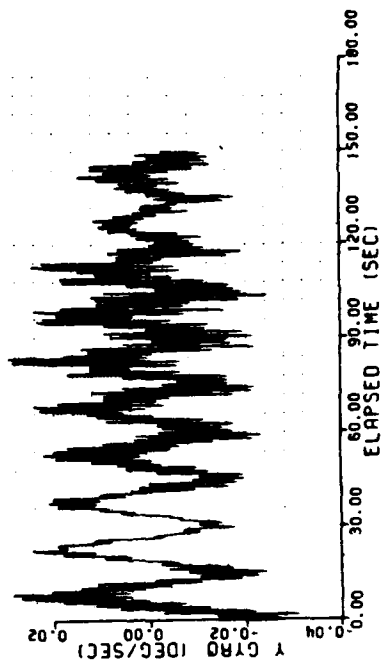
START TIME =16:26:24.641 Z



START TIME =16:26:24.641 Z



(a)



(b)

Figure 4. Measured Pendulation Rates



START TIME =16:26:24.641 Z

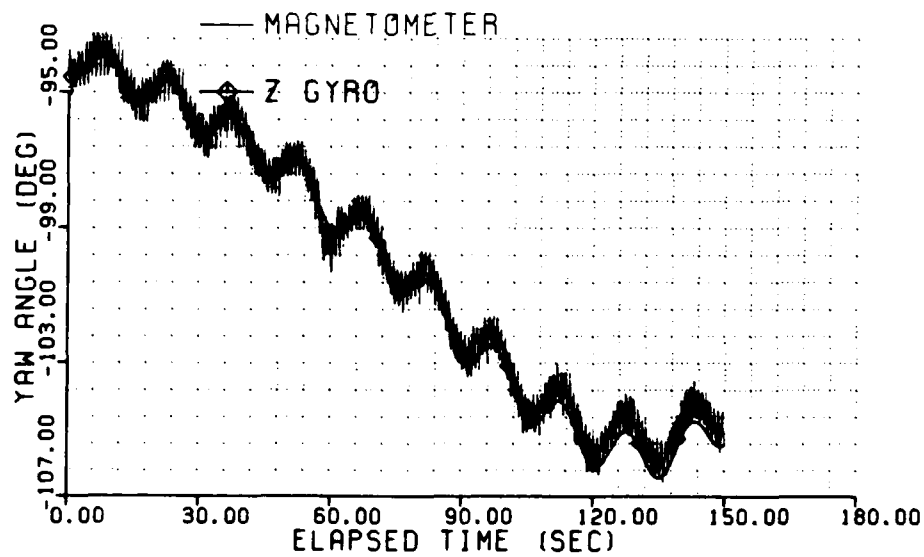
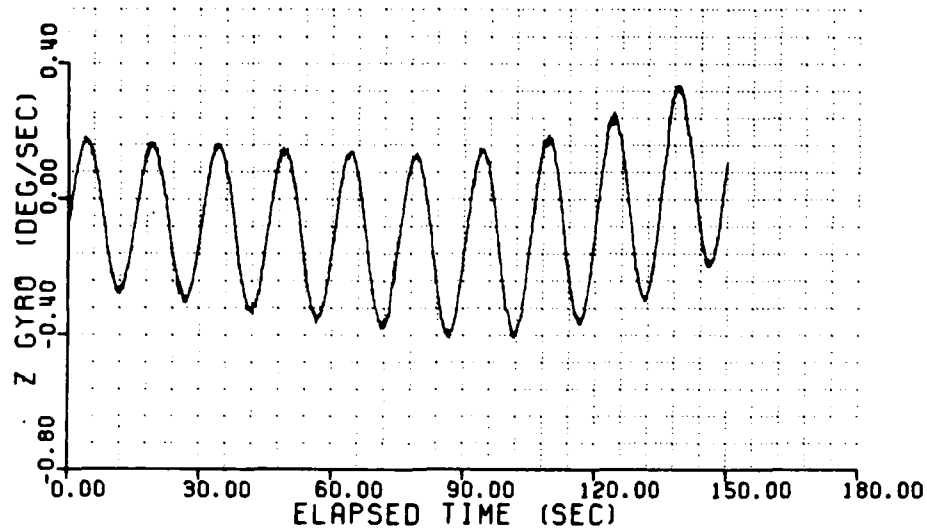


Figure 5 Measured Azimuthal Rotations

START TIME = 16:26:24.641 Z

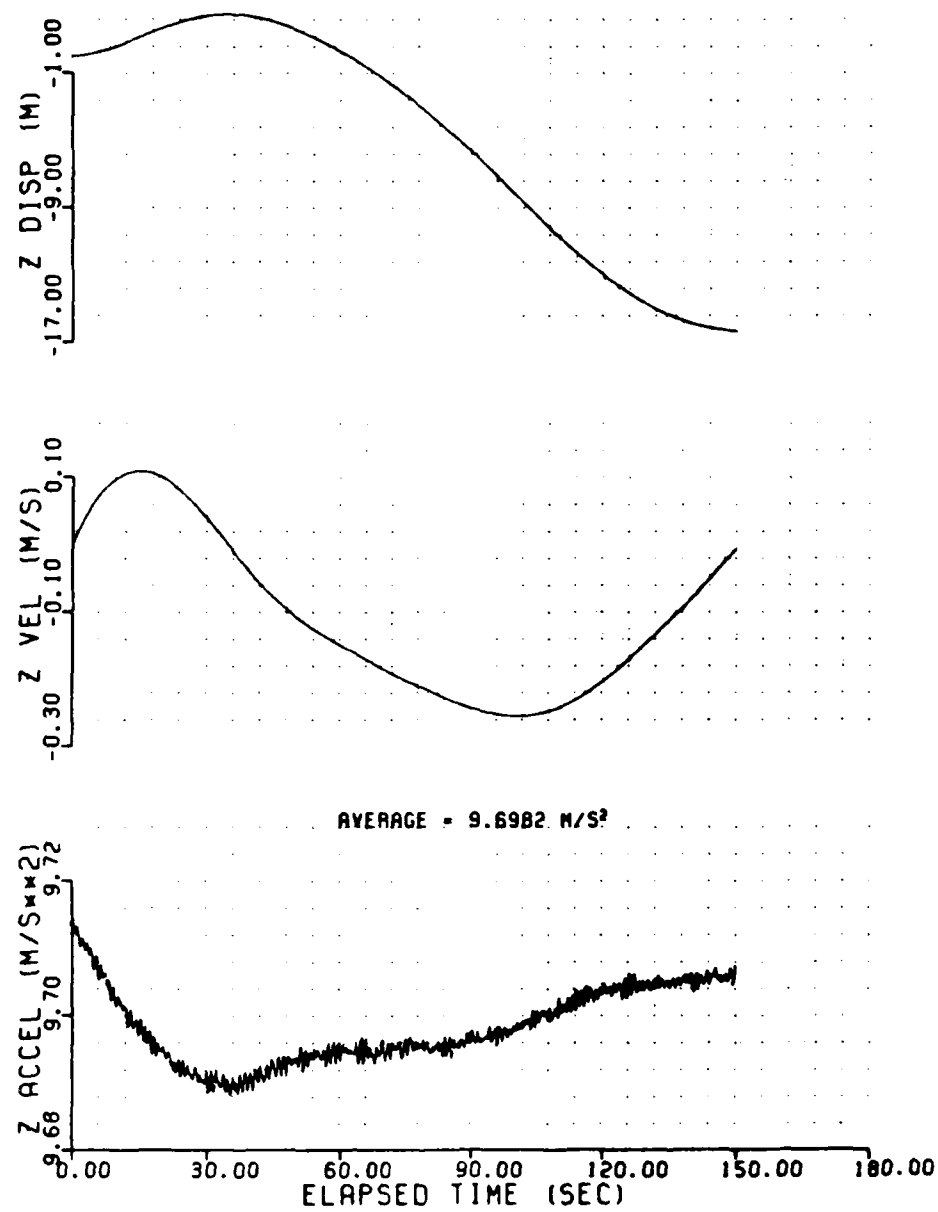


Figure 6. Measured Vertical Acceleration

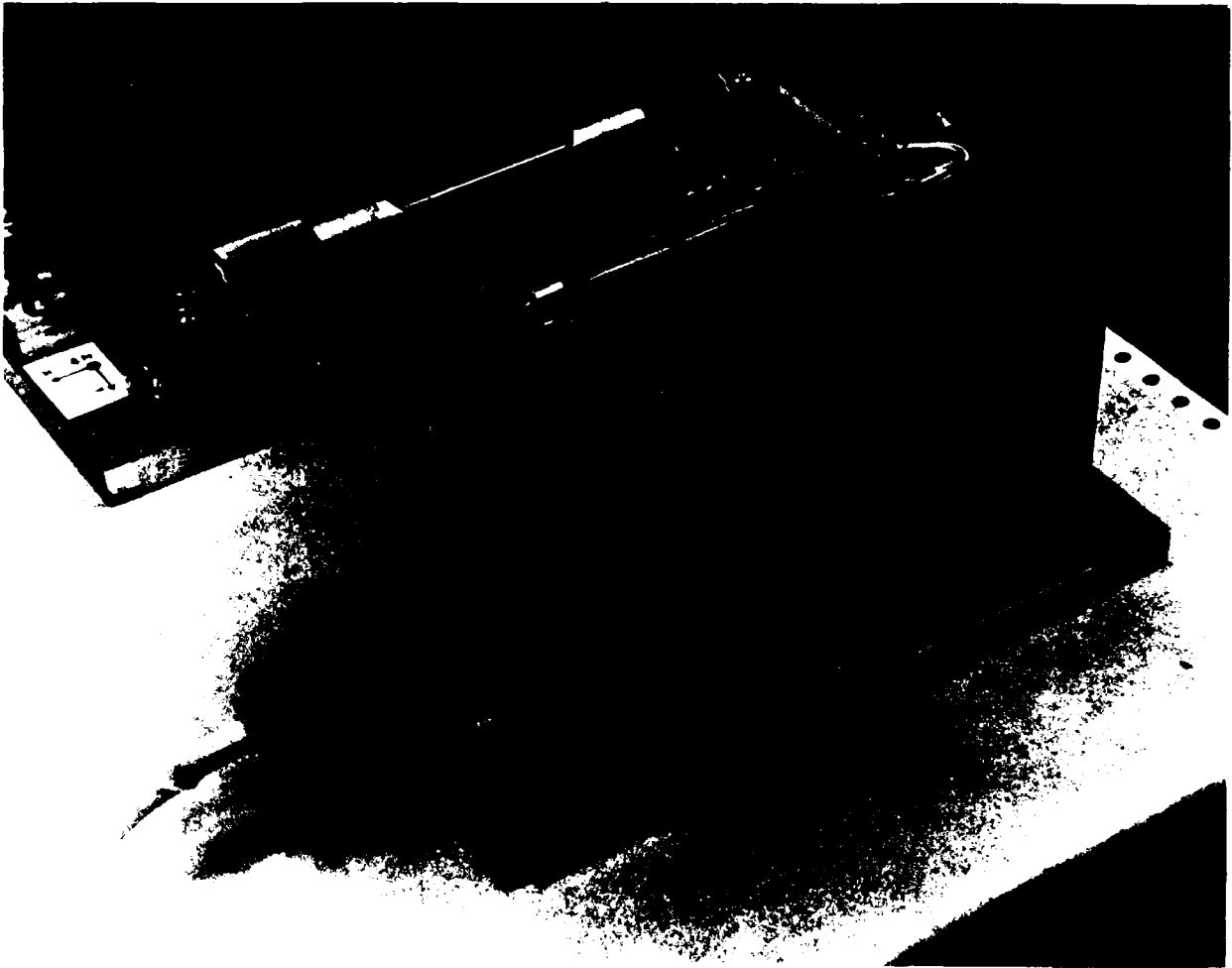


Figure 7: Abbott power supply and DC-DC converter

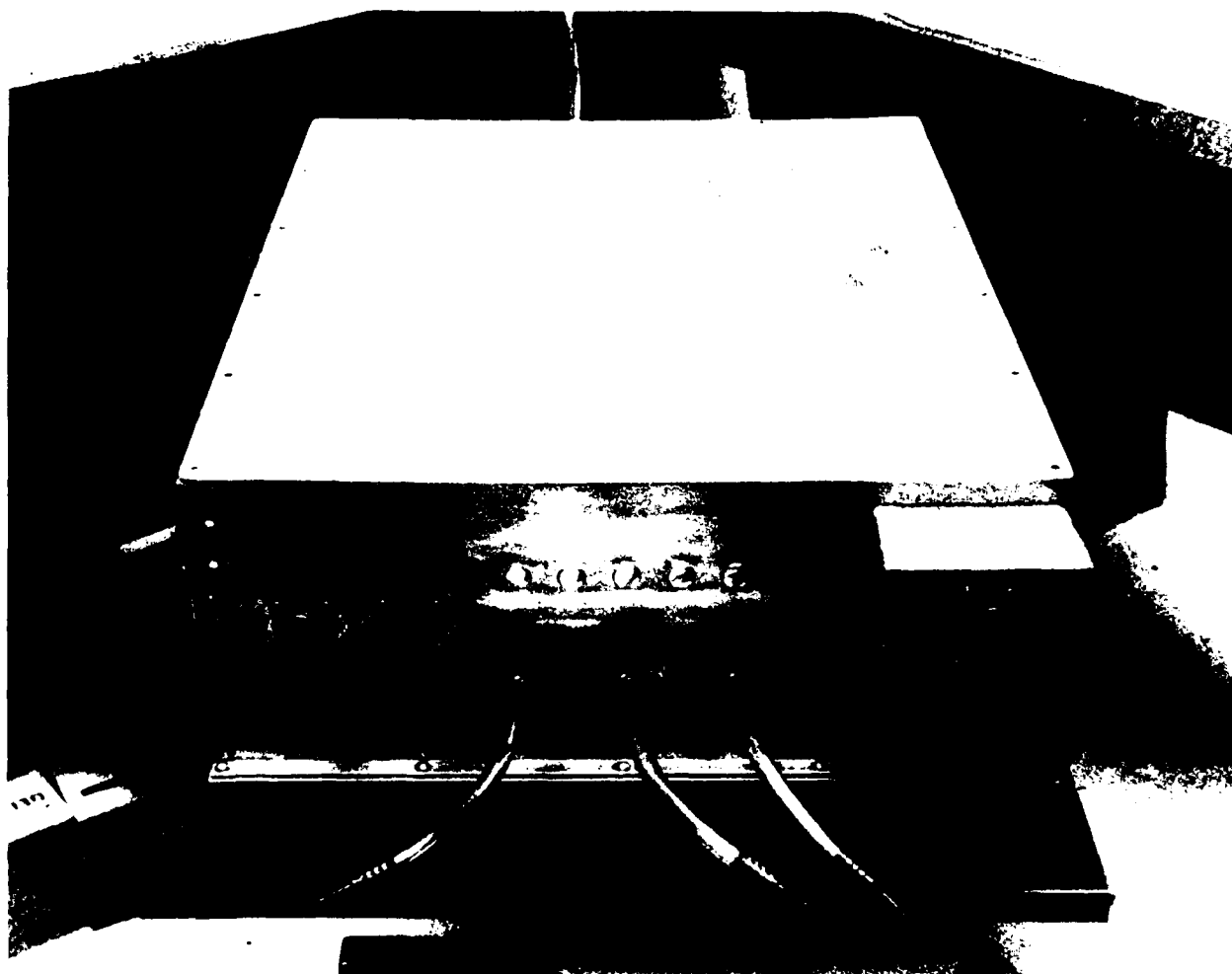


Figure 8: Tethered balloon instrument package

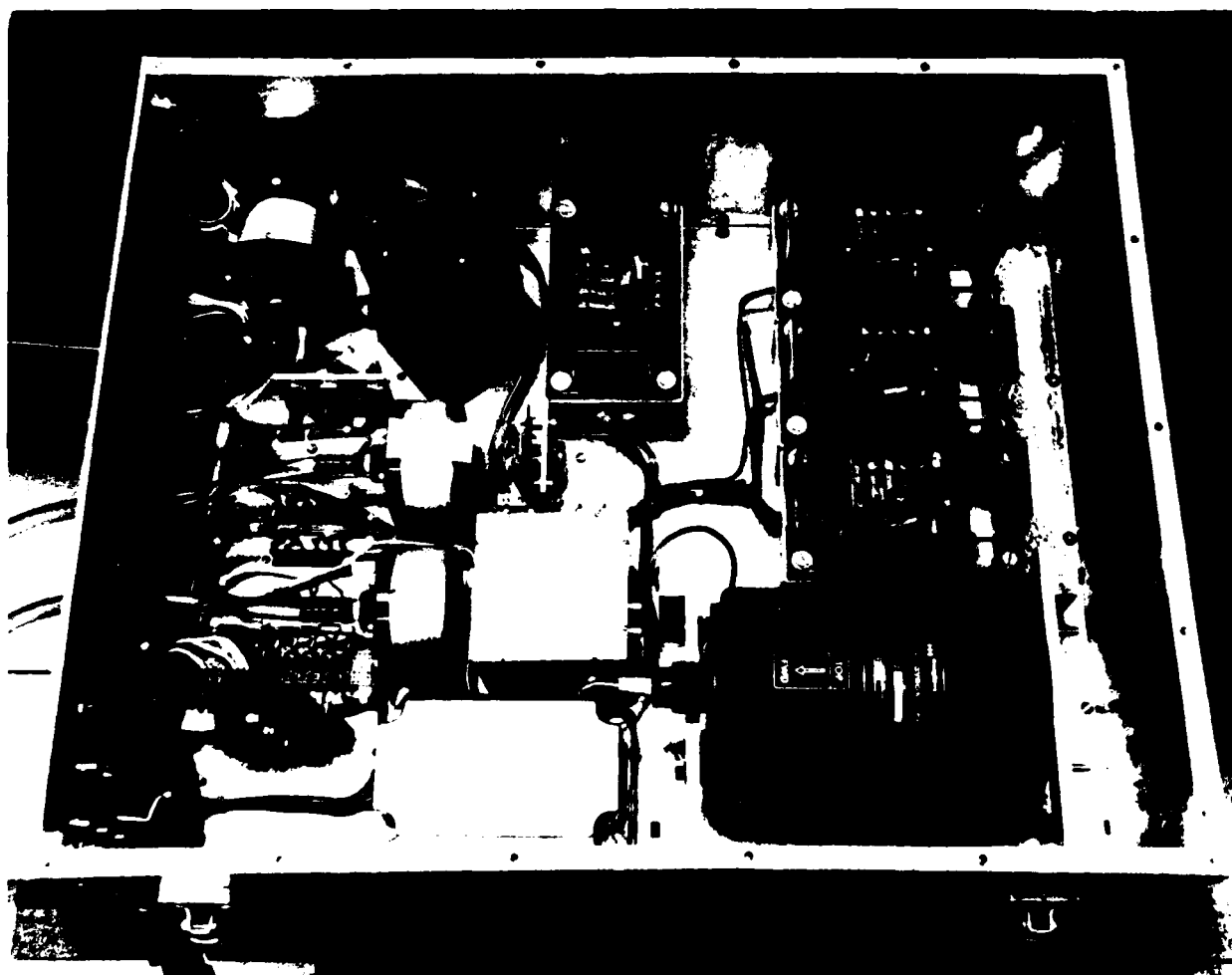


Figure 9: Tethered balloon instrument package interior

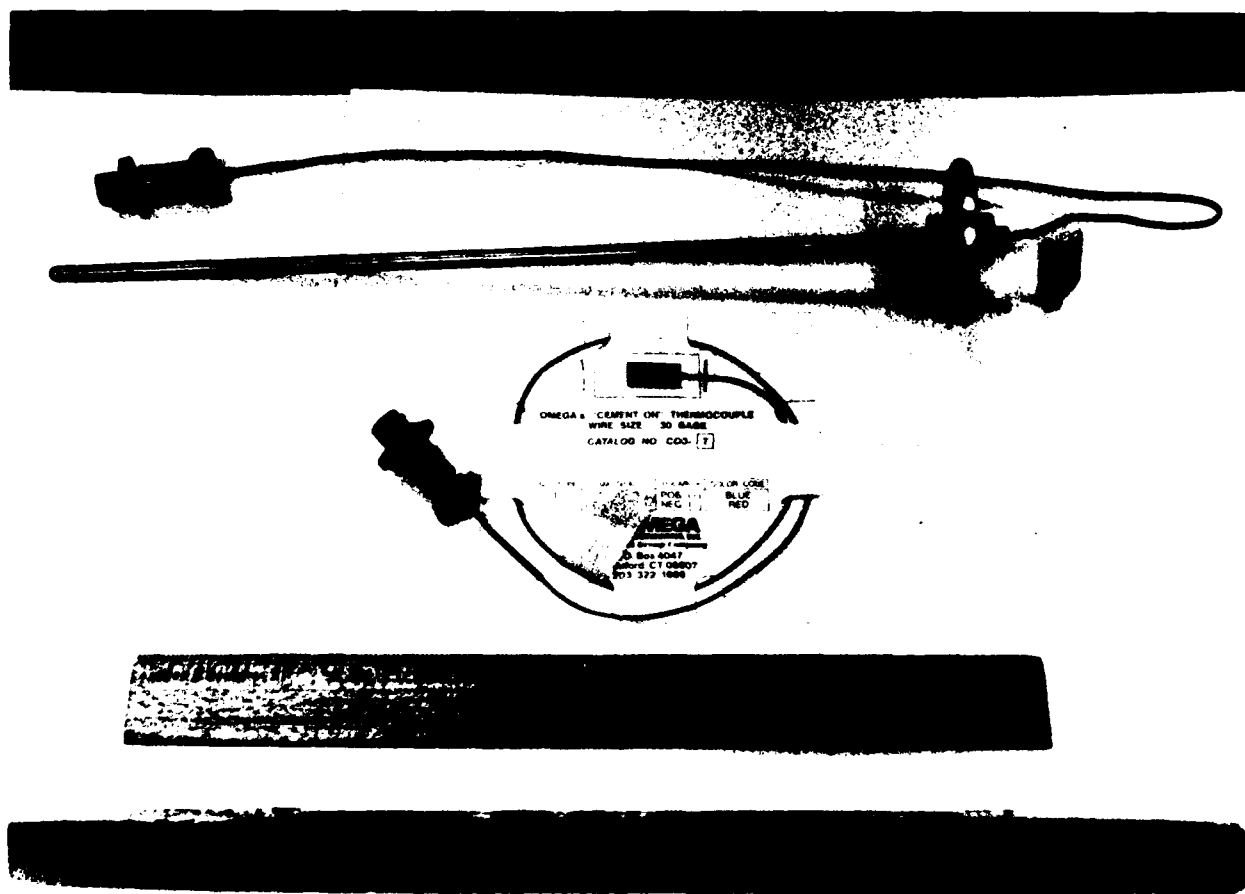


Figure 10: Gas thermocouple (top); skin thermocouple (bottom)

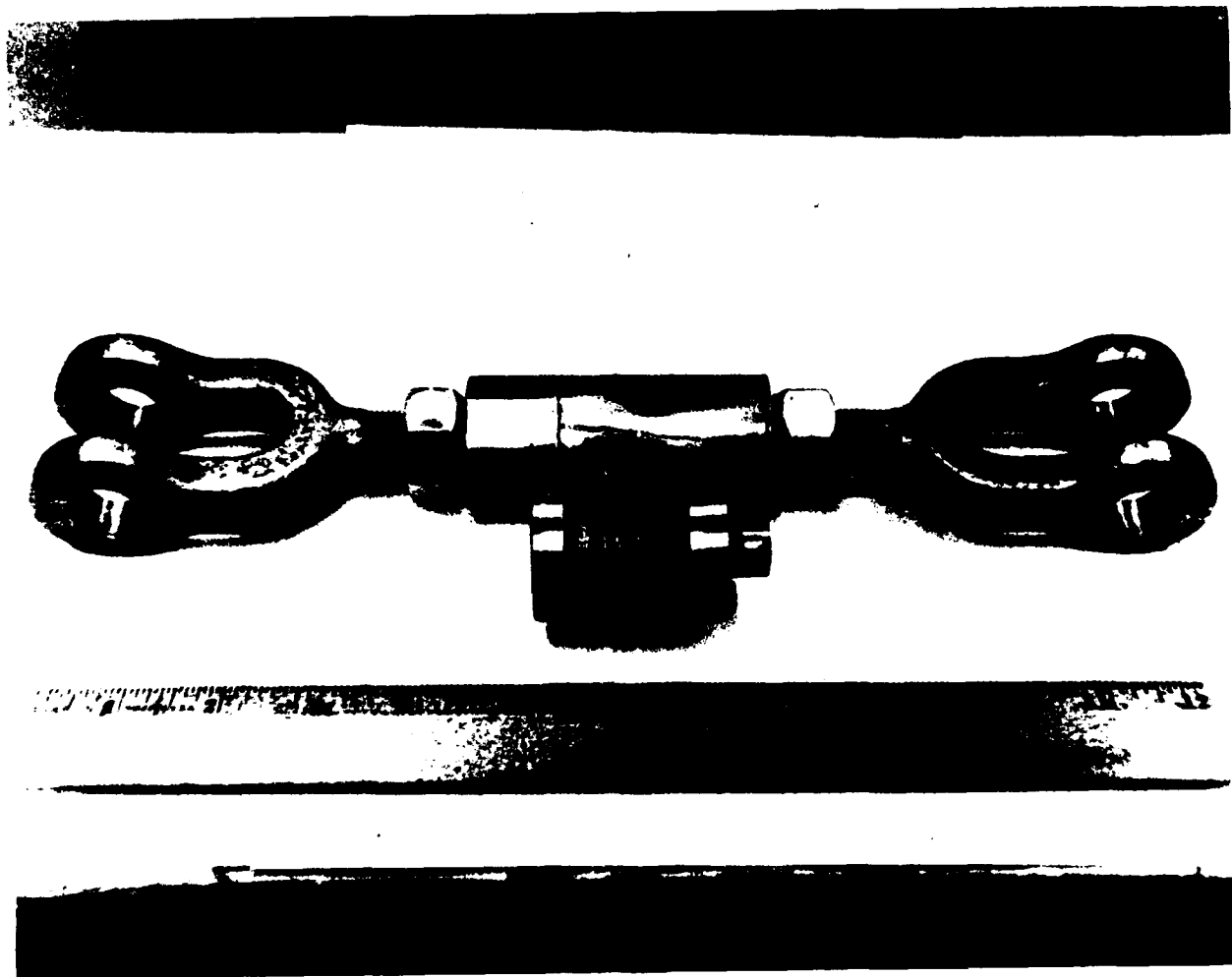


Figure 11: Sensotec load cell

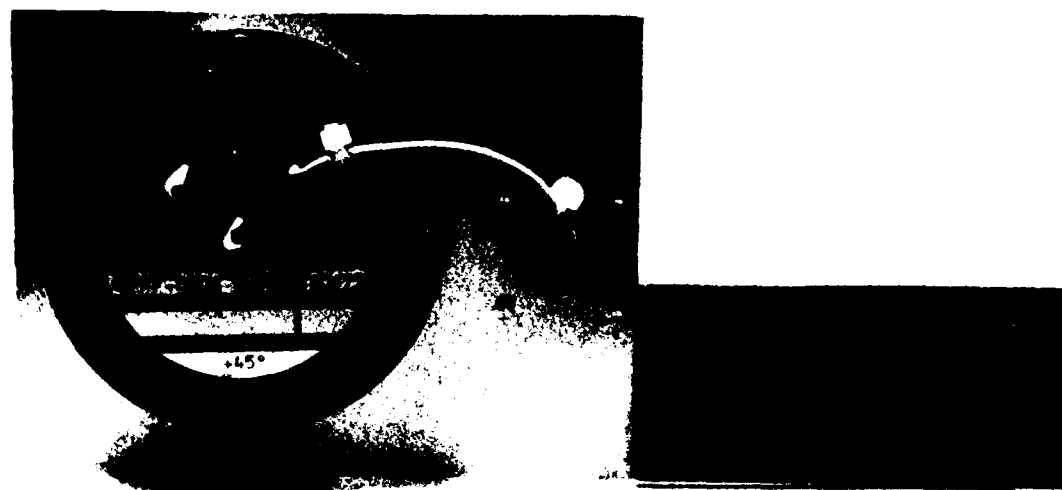
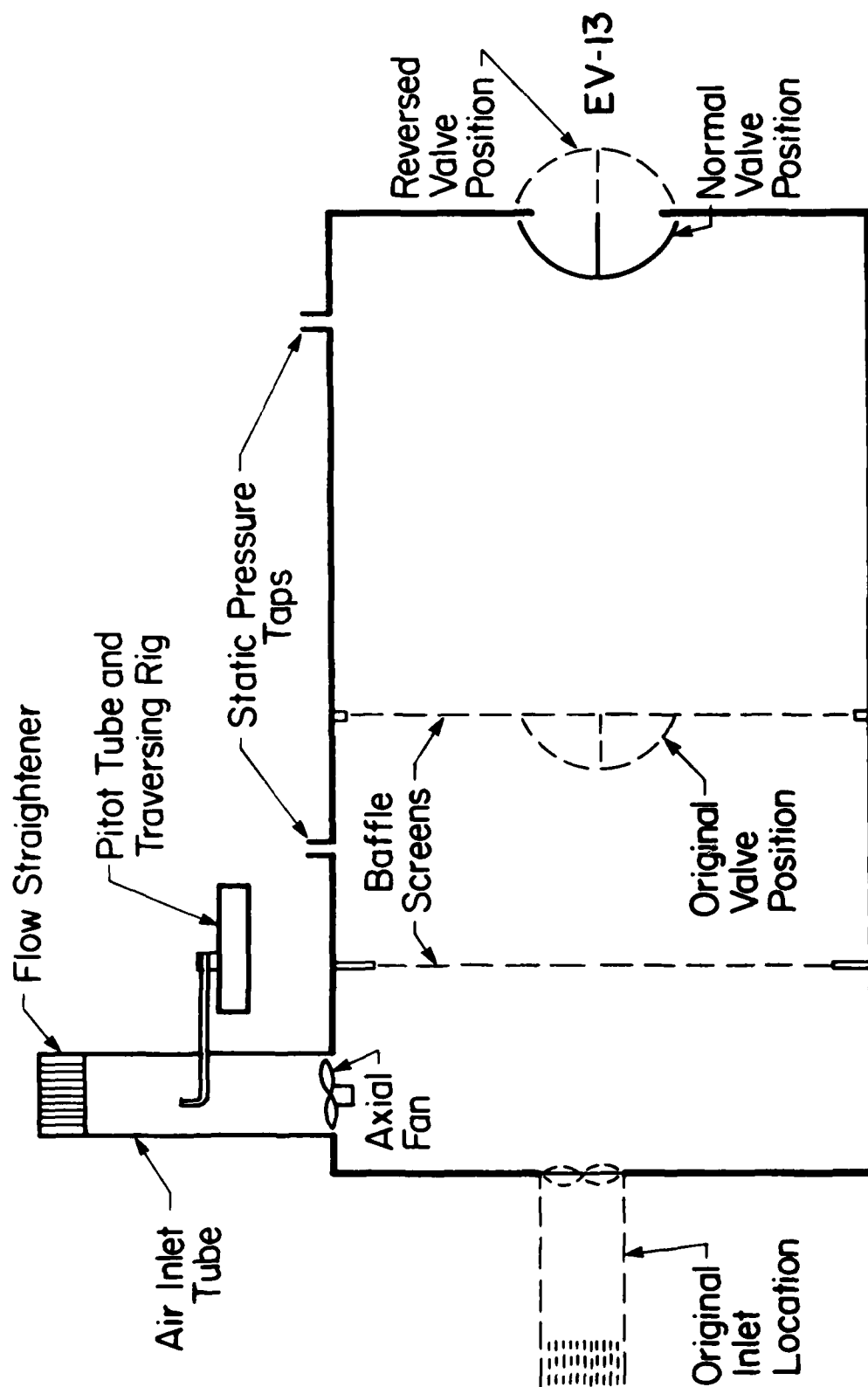


Figure 12: Humphrey pendulum and mounting bracket





EV-13 TEST APPARATUS ARRANGEMENT

Figure 13

# EV-13 HELIUM VALVE PERFORMANCE

## Mass Flow Rate vs. Pressure Difference

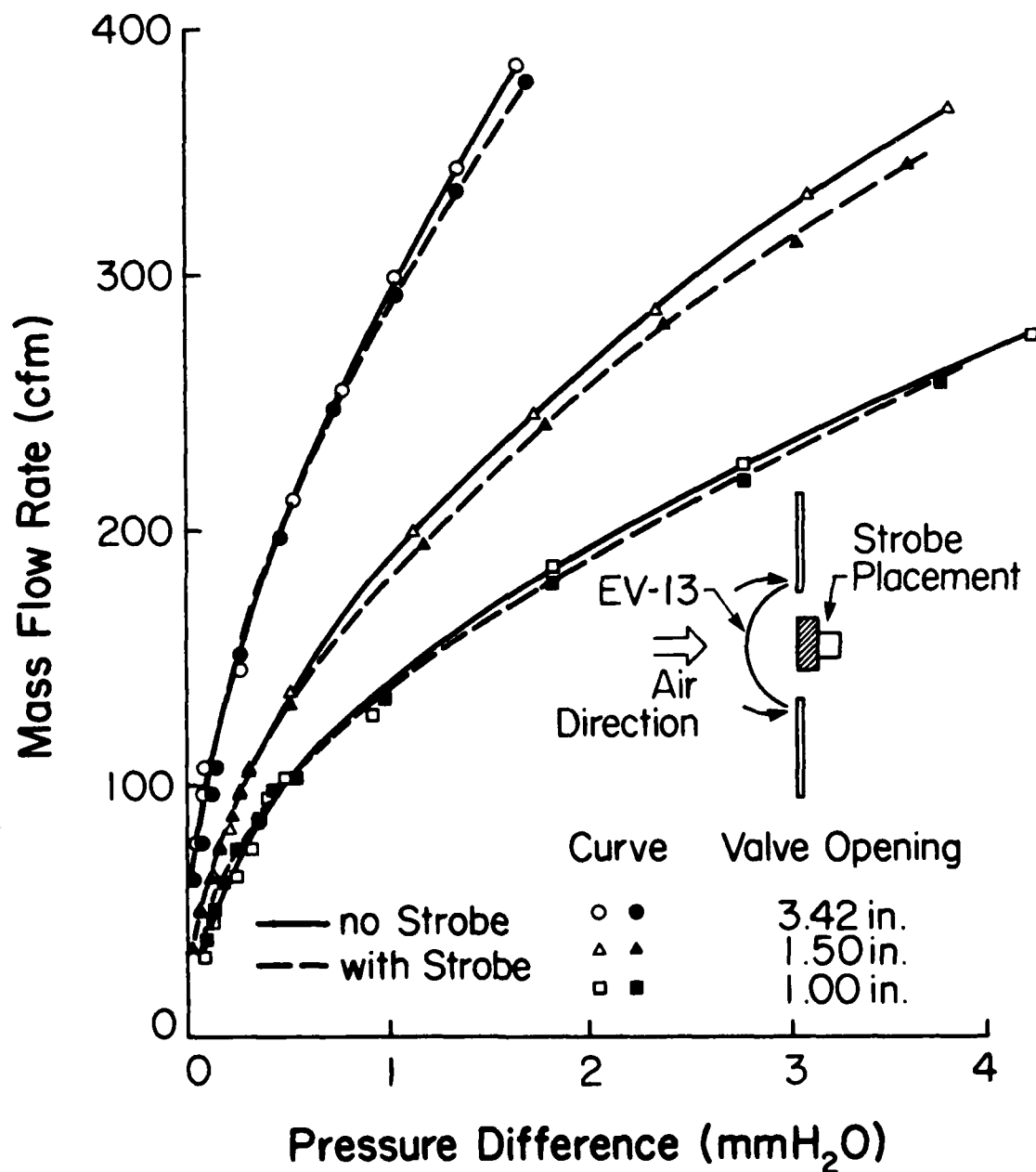


Figure 14

# EV-13 HELIUM VALVE PERFORMANCE

## Low Pressure Difference

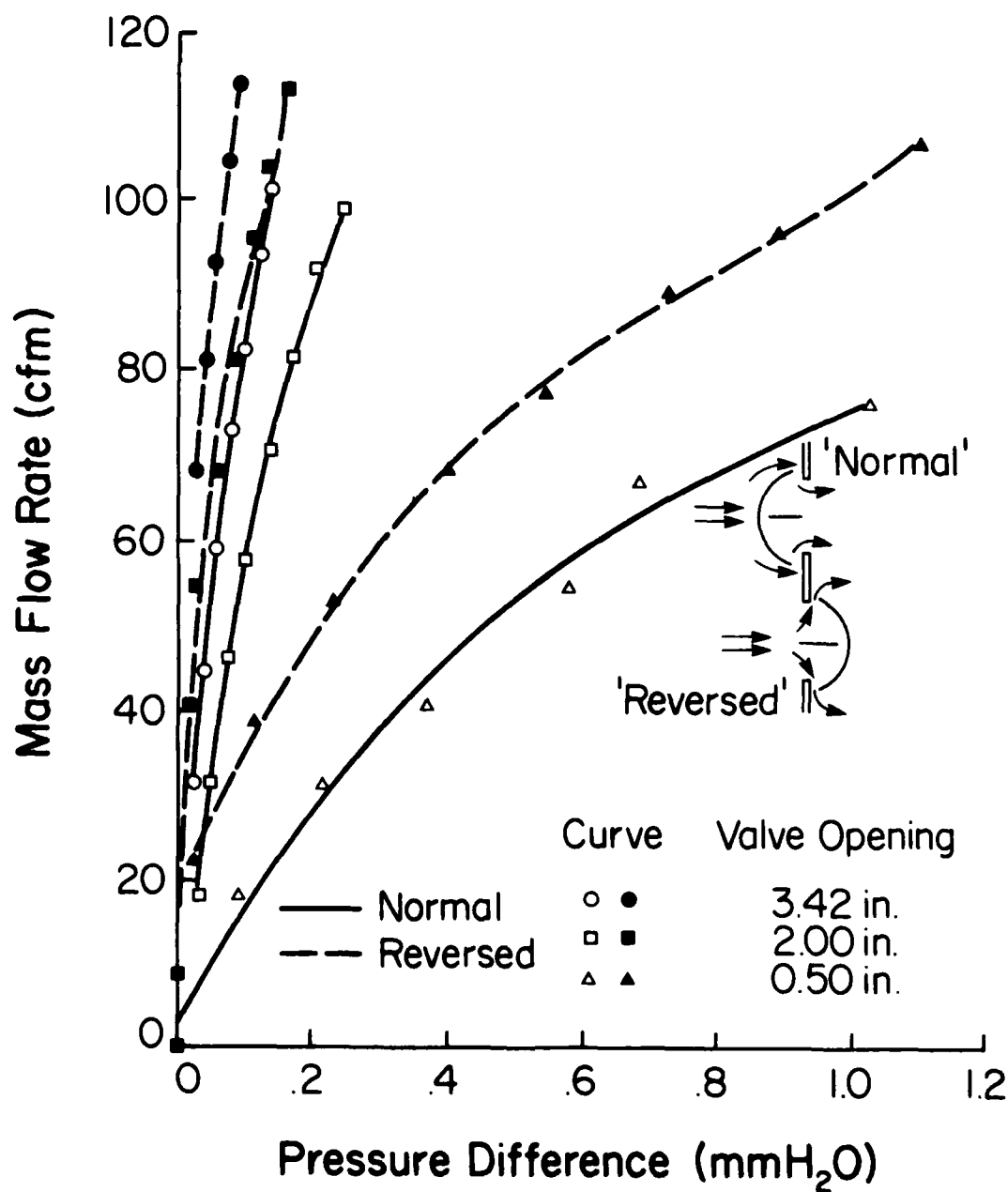


Figure 15

# EV-13 HELIUM VALVE PERFORMANCE

## High Pressure Difference

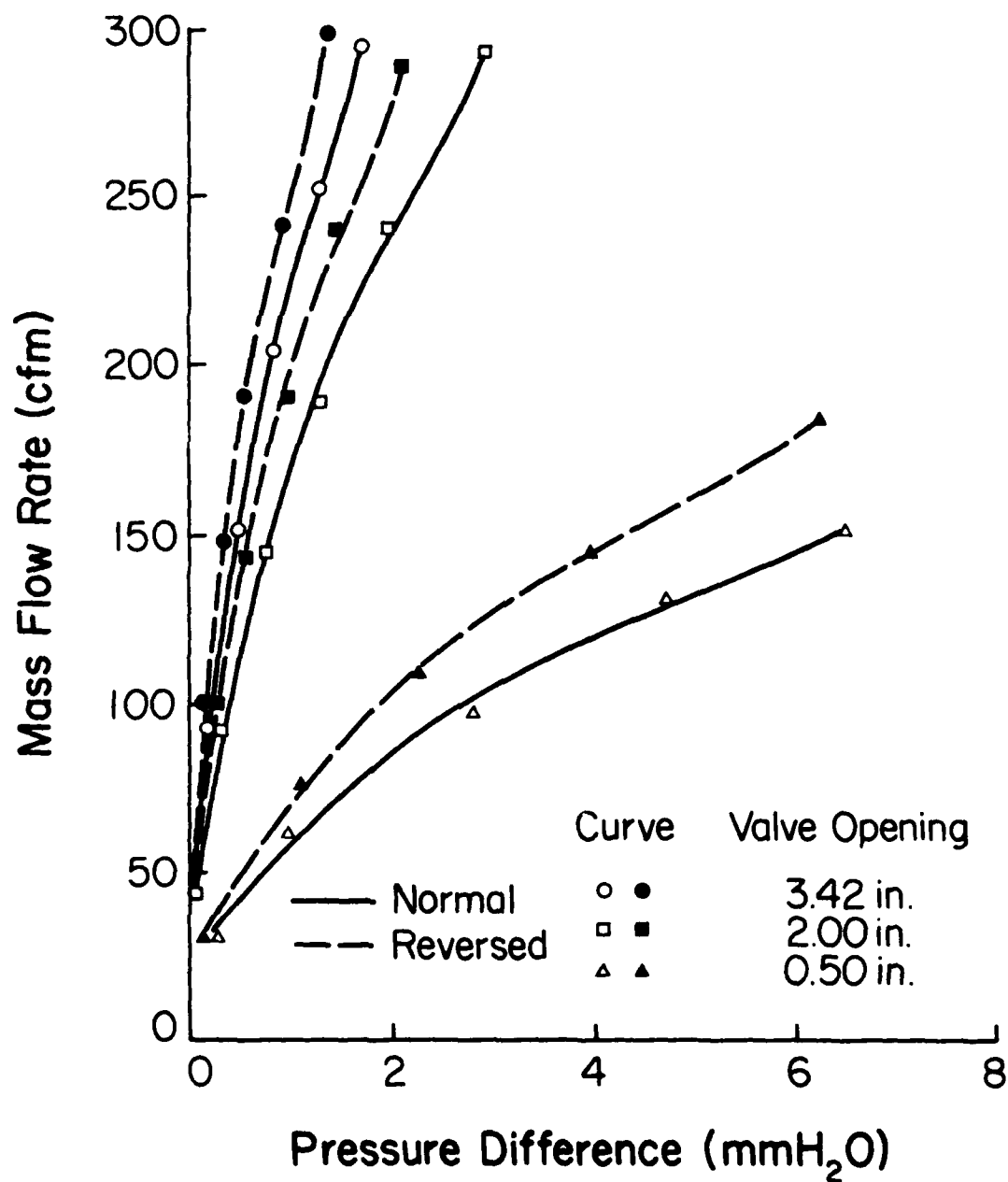


Figure 16

# EV-13 HELIUM VALVE PERFORMANCE

## Low Mass Flow Rate

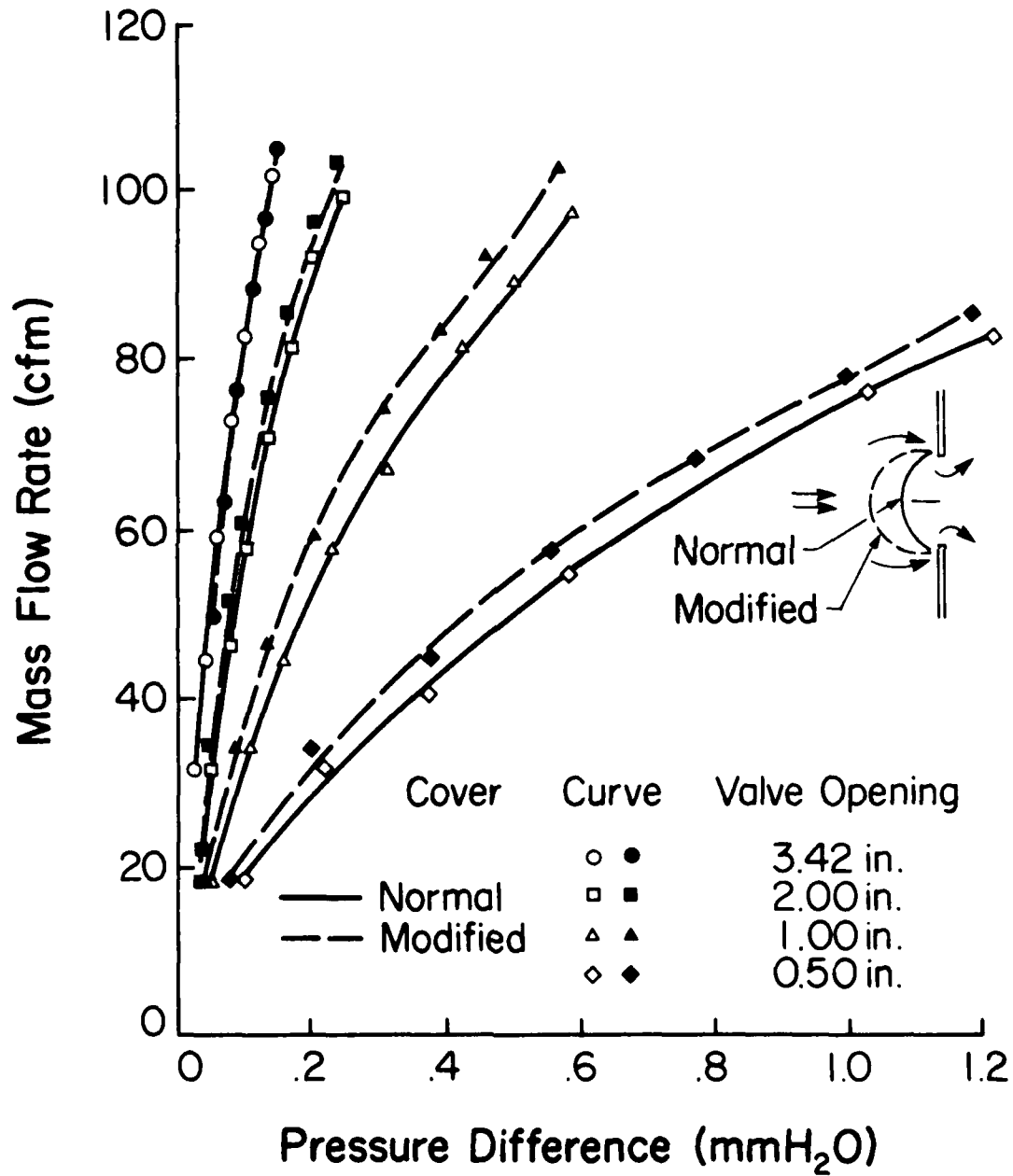


Figure 17

# EV-13 HELIUM VALVE PERFORMANCE

## High Mass Flow Rate

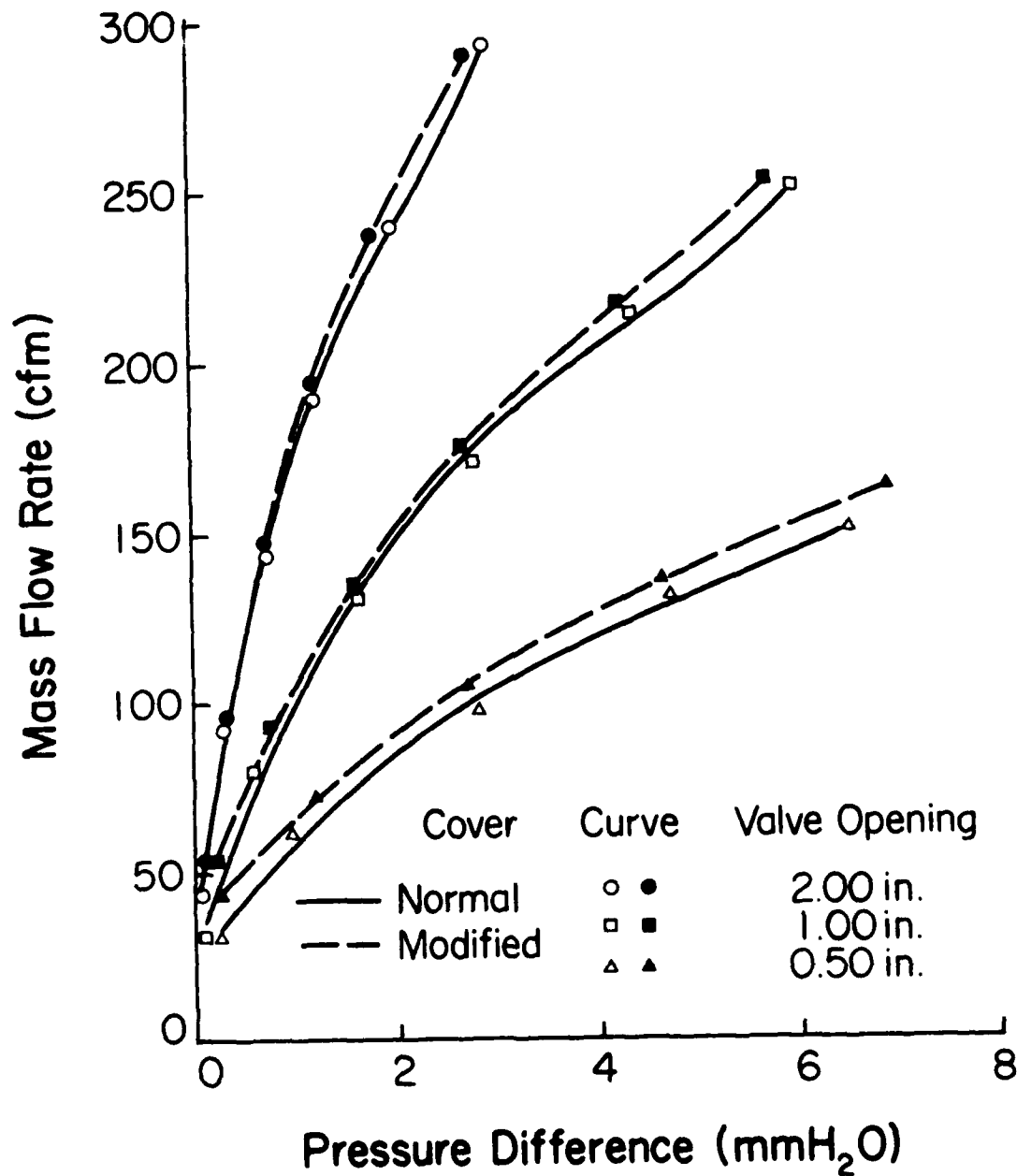


Figure 18

## EV-13 HELIUM VALVE PERFORMANCE

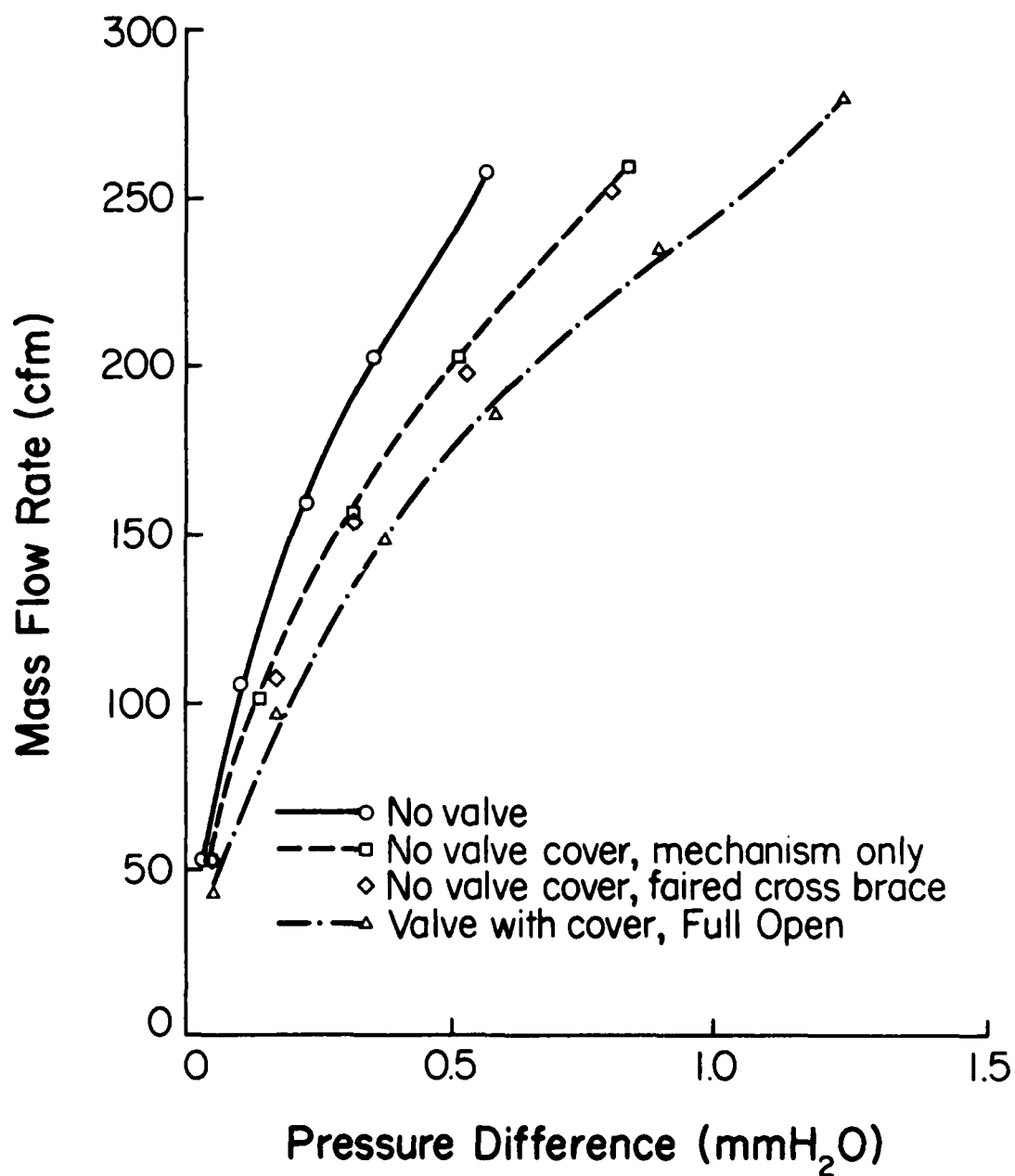


Figure 19

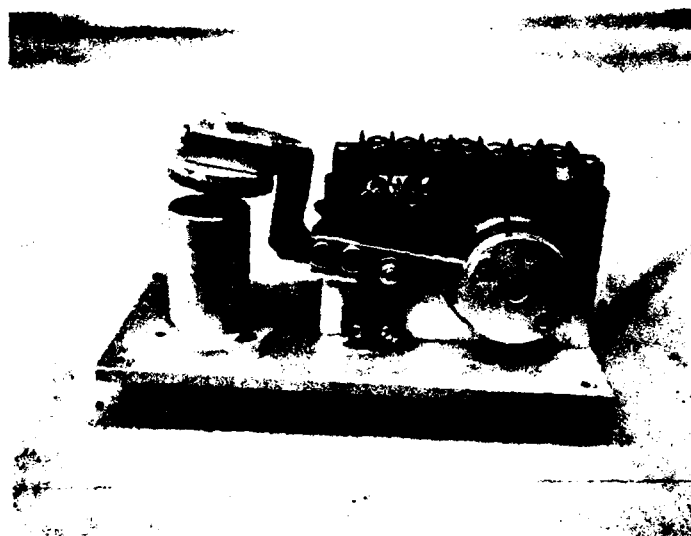


Figure 20. Ballast Valve, BV-4, with Modified Lever Arm



Figure 21. Ballast Valve, BV-4, with Potentiometer Coupled to Motor Shaft



# EV-13 HELIUM VALVE PERFORMANCE

<u>VALVE OPENING</u>	<u>PRESSURE DIFFERENCE</u>	<u>MASS FLOW RATE (cfm)</u>		<u>% DIFFERENCE</u>
(in)	(mmH <sub>2</sub> O)	Normal	Reversed	
3.42	.1	106.01	107.95	1.8
3.42	.4	(186)	(210)	12.9
3.42	1	297.74	(340)	14.2
3	.1	95.69	99.11	3.6
3	.4	(171)	202.11	18.2
3	1	(290)	(314)	8.3
3	1.5	351.31	379.81	8.1
2.5	.1	86.55	89.39	3.3
2.5	.4	(166)	(188)	13.2
2.5	1	257.01	(290)	12.8
2.5	1.5	(321)	(363)	13.1
2	.1	75.23	77.42	2.9
2	.4	138.27	(164)	18.6
2	1	(236)	(264)	11.9
2	2	(326)	(364)	11.7
1.5	.1	63.21	68.27	8
1.5	.4	(120)	(140)	16.7
1.5	1	(186)	(214)	15.1
1.5	2	(266)	(300)	12.8
1.5	2.5	(328)	(370)	12.8
1	.1	46.52	56.98	22.5
1	.4	93.04	109.48	17.7
1	1	(144)	(170)	21.4
1	2	(188)	(238)	26.6
1	3	(230)	(286)	24.3

( ) Indicates a value interpolated from the graphs.

TABLE 1

END

DT/C

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